THE ARC-SIZE ILLUSION AS APPLIED TO PLANAR DISPLAYS OF AIRCRAFT TRAFFIC INFORAMTION

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Shorter arcs are perceived as having less curvature (i.e., they are "perceptually flattened"), and this phenomenon has been labeled the *Arc-size Illusion*. This illusion was explored as it relates to planar displays of traffic information. Such displays often represent intent and/or history information with lines. Participants were presented with aircraft traveling on curvilinear paths, and their estimations of future aircraft location were examined. There were three major findings from the study. *First*, the data suggest that "perceptual flattening" and the Arc-size Illusion do indeed affect predictive judgments about aircraft on curvilinear paths. *Second*, and most surprising, the data suggest that increasing the size of the arc with a history line does NOT lessen "perceptual flattening." *Third*, the data suggest that "perceptual flattening" is especially pronounced when predictor length is relatively short and the judgment location is relatively far. However, the effect of the predictor length essentially disappears when the judgment location is at a distance that is proportional to the predictor length.

INTRODUCTION

The *Arc-size Illusion* is a perceptual phenomenon in which smaller arcs are perceived as flatter than longer arcs that have the same amount of curvature. For example, each of the three arcs in Figure 1 originate from a circle of the same radius, but arcs of smaller degrees appear flatter than arcs of larger degrees (e.g., Arc C appears flatter than Arc A and Arc B, or put another way, Arc C appears as if it originates from a circle with a larger radius).

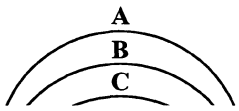

Figure 1. An illustration of the Arc-size Illusion

Virsu conducted a total of three studies in which he introduced the illusion and examined various conditions as they relate to the illusion. In the *first* study (Virsu, 1971a), he found that arcs of lesser degrees were perceived as flatter, despite the fact that they originated from circles of the same radius. In addition, Virsu found that, at greater judgment distances, the errors associated with shorter arcs were especially pronounced. In a *second* study, Virsu (1971b) used the forced choice method. Again, the Arc-size Illusion was demonstrated. The smallest arc size (9 deg) yielded a 35.2% difference between the point of subjective equality and the true radius size, while the largest arc size (342 deg) yielded a difference of only 3%. In a *final* study, Virsu and Weintraub (1971) again found that shorter arcs are perceived as flatter than longer arcs. In addition, when the arcs originated from circles of smaller radii, the errors associated with shorter arcs were especially pronounced.

While this illusion is interesting at the level of basic research, it also may have an important impact in the applied domain. Planar displays of traffic information often represent intent and/or history information with lines. For example, intent information is available on the cockpit display of traffic information (CDTI) (c.f., Johnson, Battiste, Deizell, Holland, Belcher, & Jordan, 1997; Johnson, Battiste, & Holland Bochow, 1999), and history information is available on the air traffic controller's radarscope. Generally speaking, *predictor lines* are lines that represent a "best guess" at the future location of a vehicle or object, and *history lines* are lines that represent the previous location of the vehicle or object. When aircraft have been or are currently on a *curvi*linear path, judgments about future aircraft location may be affected by the Arc-size Illusion. An example of this potential problem is illustrated in Figure 2.

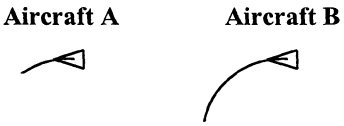

Figure 2. Predictor lengths for a constant time period (e.g., five minutes), a constant rate of turn, but a variation in aircraft velocity.

Aircraft A is traveling slower than Aircraft B. Therefore, in the same amount of time, Aircraft A will travel through less airspace than Aircraft B. Because predictor lines usually represent a constant time period, the predictor line for Aircraft A is shorter. Both aircraft in Figure 2 have the same rate of turn. However, due to the Arc-size Illusion, the graphical representation of the prediction *appears* to suggest that Aircraft A will follow a straighter trajectory than Aircraft B.

The present experiment was aimed at exploring the extent to which the Arc-size Illusion may affect judgments on instruments such as the CDTI. Another goal was to explore whether increasing the length of an arc, by the addition of a history line, serves to decrease illusory "flattening." In the context of traffic displays, the history line certainly is relevant information. If it serves to offset the illusion, it is a convenient and reasonable method for doing so. Finally, this experiment allowed for an investigation of other factors (i.e., circle size and judgment location) that might affect the perceived curvature of predictor and history lines.

EXPERIMENT ONE

Method

Independent variables. Six levels of *Predictor Length* (25, 32.5, 40, 47.5, 55, and 62.5 deg) were combined with two levels of *History Information* (Absent and Present) to create twelve conditions. For illustrative purposes, the stimuli from four of these conditions are presented in Figure 3.

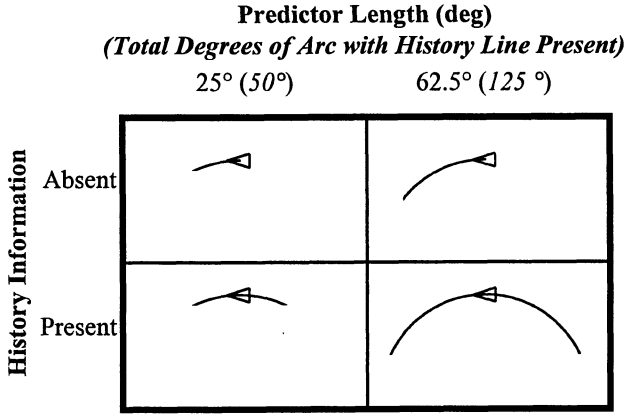

Figure 3. Illustration of the stimuli in the largest and smallest Predictor Length conditions as well as an illustration of the History Information conditions (Absent and Present). Stimuli are not drawn to scale.

Two additional independent variables were included in the study. The physical size of an arc depends not only on its degrees of arc, but it also depends on the size of the circle from which the arc originates. Therefore, *Circle Size* was included as a third independent variable, and its two levels were Large (radius of 19 mm) and Small (14 mm).

The fourth, and final, independent variable was *Judgment Location*. For illustrative purposes, Figure 4 presents the three levels of Judgment Location (Constant Proportion, Constant Distance, and Constant Location) for two of the six levels of Predictor Length.

The three levels of Judgment Location represent different locations of the response line. The Constant Proportion condition was created by taking the degrees of the predictor and dividing them in half. The resulting degrees of arc were then used to determine the distance of the response line from the end of the predictor. For example, in the Constant Proportion condition, the response line was placed 12.5 degrees from the end of a 25-degree predictor. This condition represents judgments over a constant time frame. In practical terms, an aircraft with a relatively long predictor is traveling faster than an aircraft with a relatively short predictor. Therefore, given a constant amount of time, judgments for the faster moving aircraft will be relatively farther from the end of the predictor than judgments for the slower moving aircraft. In the Constant Distance condition, the response line was always located 30 deg from the end of the predictor. Finally, unlike the former two conditions, the position of the response line did not vary in the Constant Location condition.

The three conditions of Judgment Location also can be understood as variations in the amount of empty space between the end of the predictor and the response line. In the Constant Proportion and Constant Location conditions, the empty space changes relative to degrees of arc. Specifically, when the arc is small (as in the 25 deg condition), the response line is relatively close to the predictor in the Constant Proportion condition and relatively far in the Constant Location condition. However, when the arc is large (as in the 62.5 deg condition), the relation is exactly the opposite; the response line is relatively far from the predictor in the Constant Proportion condition and relatively close in the Constant Location condition. In the Constant Distance condition, the space between the predictor and the response line is simply always the same.

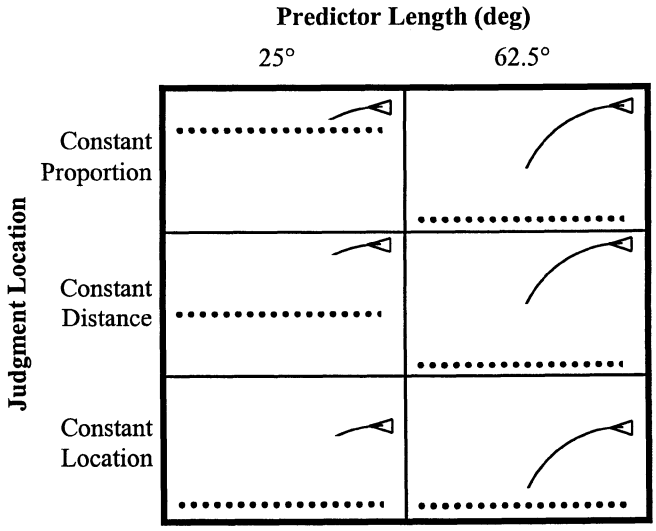

Figure 4. Illustration of stimuli in the three Judgment Location conditions, with two levels of Predictor Length shown for illustrative purposes. Stimuli are not drawn to scale.

Experimental Design. The experimental design was a 6 X 2 X 2 X 3 (Predictor Length X History Information X Circle Size X Judgment Location). This design resulted in a total of 72 stimuli, and because all independent variables were within-participants variables, each participant responded to all 72 stimuli.

Participants. Eight volunteers participated in the experiment. Ages of the participants ranged from approximately 20 to 40 years, and none of the participants had a background in aviation.

Procedure. Each participant was given a paper-and-pencil packet containing the stimuli. Each stimulus appeared on a separate sheet of paper and was positioned in the center of the sheet. The participants were told to imagine being an air traffic controller or a pilot monitoring traffic. The concepts of both a predictor line and a history line, as they relate to aviation, were explained to the participants (i.e., lines that

represent a "best guess" at the future location of an aircraft and lines that represent the previous location of an aircraft, respectively). They were asked to determine the location at which each aircraft would intersect with the dotted line and to place a hash mark on a dot or between two dots to signify their judgment. The experimenter explained that a pilot or an air traffic controller sometimes must make quick, intuitive judgments regarding the future location of aircraft. Therefore, they were asked not to use their pencil for any purposes other than drawing the hash mark (i.e., they were asked not to "fill in" the rest of the circle with their pencil). The participants viewed only one stimulus at a time, and the experimenter used a sample stimulus to insure each participant understood the task.

Dependent Variable. The data were coded in terms of *Error*. Specifically, the veridical radius was subtracted from the perceived radius. Therefore, a positive number represents "flattening, " zero suggests the curvature was perceived perfectly, and a negative number suggests that the arc was perceived as having too much curvature (i.e., the opposite of "flattening").

Results

In terms of overall performance, the radius of the circle from which the arcs originated was overestimated by 2.15 mm, and this grand mean was significantly different from zero, $F(1, 7) = 46.02$, $p < .001$. Therefore, arcs were perceived as too flat in general. Figure 5 illustrates that shorter arcs were perceived as flatter than longer arcs, $F(5, 35) = 8.55$, $p < .001$. This finding suggests that the Arc-size Illusion indeed affects tasks like those found in the aviation domain (e.g., the pilot using the CDTI or the air traffic controller).

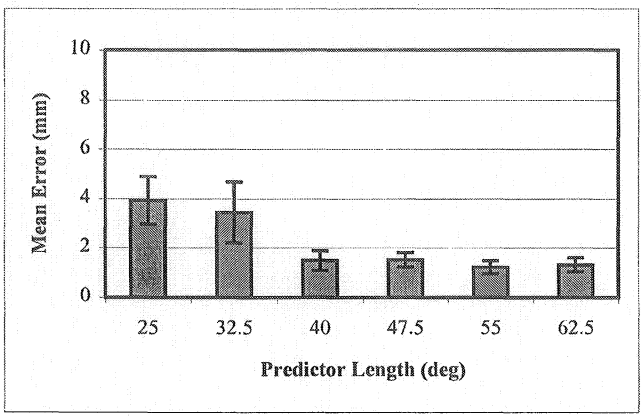

Figure 5. Mean Error as a function of Predictor Length. Intervals around each mean are confidence intervals of 95%.

The main effect of History Information was not significant, $F(1, 7) = 0.04$, $p > .05$. The Predictor Length X History Information interaction was significant, $F(5, 35) = 3.62$, $p < .01$. This interaction is illustrated in Figure 6.

Four specific comparisons are especially interesting in Figure 6. *First*, in the 25 deg Predictor Length condition, the History Information Absent and History Information Present conditions are *not* significantly different. This lack of significant difference is surprising, since the total degrees of arc in the History Information Present condition are twice that of the History Information Absent condition. *Second*, the condition in which the predictor was 25 deg and the history line was present is significantly different than the condition in which the predictor was 47.5 deg and the history line was absent. This significant difference is surprising, since the total degrees of arc are almost identical (i.e., 50 and 47.5 deg of arc respectively). *Third*, in the 32.5 deg Predictor Length condition, the History Information Absent and History Information Present conditions are *not* significantly different. Like the first observation, this lack of significant difference is surprising, since the degrees of arc in the History Information Present condition are twice that of the History Information Absent condition. *Fourth*, when the predictor was 32.5 deg and the history line was present, responses were significantly different from the condition in which the predictor was 62.5 deg and the history line was absent. Similar to the second observation, this significant difference is surprising, since the total degrees of arc are almost identical (i.e., 65 and 62.5 deg of arc respectively). Taken together, these four observations suggest that participants made no use of the history information.

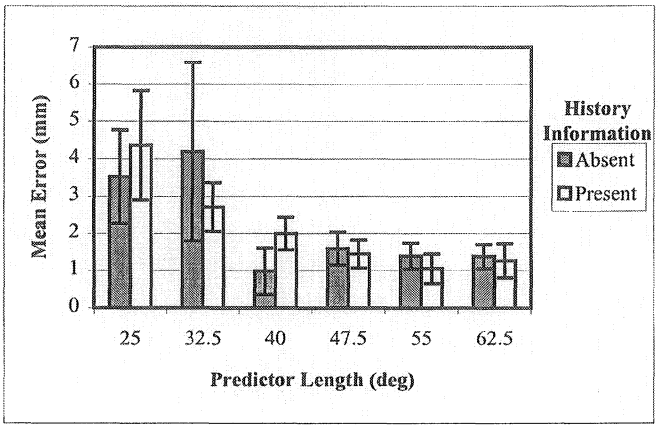

Figure 6. Mean Error as a function of Predictor Length and History Information. Intervals around each mean are confidence intervals of 95%.

The mean error was 2.41 mm for small circles and 1.90 mm for large circles. This main effect was not significant, $F(1, 7) = 3.68$, $p > .05$. However, the direction of the means is consistent with the findings of Virsu and Weintraub (1971). The main effect was significant when responses were coded in terms of relative error, $F(1, 7) = 12.34$, $p < .01$. Relative Error was calculated by dividing the raw error by the actual radius of the circle from which the arc originated. In other words, the Relative Error measure reflects the fact that the same amount of raw error is *relatively* greater for a smaller circle size. Of course, in a practical sense, raw error is probably of most interest. Virsu and Weintraub did find a difference between circle sizes when they examined raw error. It is possible that

the present study examined circle sizes that were too similar to yield differences when raw error was examined.

The main effect of Judgment Location was significant, $F(2, 14) = 17.80$, $p < .001$. However, the Predictor Length X Judgment Location interaction also was significant, $F(10, 70) = 6.01$, $p < .001$. This interaction is illustrated in Figure 7.

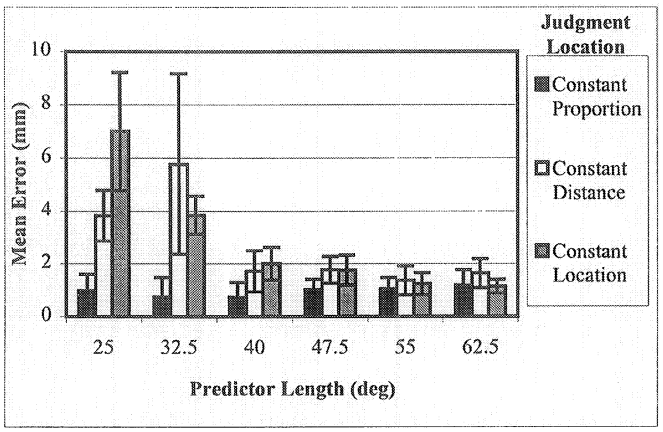

Figure 7. Mean Error as a function of Predictor Length and Judgment Location. Intervals around each mean are confidence intervals of 95%.

As illustrated in Figure 7, the Constant Distance and Constant Location conditions were significantly different from the Constant Proportion condition when the predictor length was relatively small (i.e., 25 or 32.5 deg). A more intuitive description of these results is to say that only the Constant Distance and Constant Location conditions demonstrated the Arc-size illusion. While the Constant Proportion condition did yield consistent "flattening" overall, this condition did not demonstrate the Arc-size Illusion.

This interaction is explained easily when the stimuli are considered. In the Constant Proportion condition, the response line was relatively close to the small predictors. By not requiring participants to extrapolate over great distances, the inflated error normally associated with smaller degrees of arc was offset. Although a different task was required of participants, Virsu (1971a) also found that arcs of relatively few degrees resulted in more "flattening" as judgments were moved to relatively farther locations.

EXPERIMENT TWO

Method

Experiment Two was identical to Experiment One with only two exceptions. The *first*, and most important, difference was that the task in Experiment Two involved two aircraft. Both aircraft in each pair originated from a circle of the same radius and were identical in degrees of arc. Figure 8 provides an example of the stimuli used in Experiment Two.

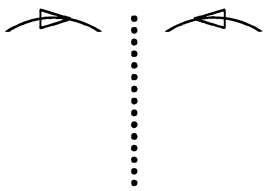

Figure 8. Example of the stimuli used in Experiment Two. Stimuli are not drawn to scale.

Participants received the same instructions as those described for Experiment One. The only difference was that they were asked to determine the location at which the two aircraft would intersect the dotted line (i.e., they were asked to determine where these two aircraft would collide).

The *second* difference was that judgment location was not varied in Experiment Two. The response line remained in the same location (i.e., as in the Constant Location condition of Experiment One). All other variables from Experiment One were examined in Experiment Two. Therefore, the design was a 6 X 2 X 2 (Length of Predictor X History X Circle Size).

Results

In terms of overall performance, the radius of the circle from which the arcs originated was overestimated by 2.58 mm, and this grand mean was significantly different from zero, $F(1, 7) = 20.59$, $p < .005$. Therefore, as in Experiment One, arcs were perceived as too flat in general. In Experiment 2, shorter arcs were perceived as flatter than longer arcs, $F(5, 35) = 12.04$, $p < .001$. This finding again suggests that the Arc-size Illusion indeed affects tasks like those found in the aviation domain (e.g., the pilot using the CDTI or the air traffic controller).

Again, the main effect of History Information was not significant, $F(1, 7) = 0.49$, $p > .05$. In Experiment Two, the Predictor Length X History Information interaction was not significant, $F(5, 35) = 1.50$, $p > .05$. However, four specific comparisons again are interesting. *First*, the History Information Absent and History Information Present conditions were *not* significantly different in the 25 deg Predictor Length condition. *Second*, the condition in which the predictor was 25 deg and the history line was present was significantly different than the condition in which the predictor was 47.5 deg and the history line was absent. *Third*, the History Information Absent and History Information Present conditions were *not* significantly different in the 32.5 deg Predictor Length condition. *Fourth*, when the predictor was 32.5 deg and the history line was present, responses were significantly different from the condition in which the predictor was 62.5 deg and the history line was absent. These four relations are consistent with those found in Experiment One, and they suggest that participants were not making use of history information.

The mean error was 2.55 mm for small circles and 2.63 mm for large circles. This main effect was not significant, $F(1, 7) = 0.06$, $p > .05$. Unlike Experiment One, the differences in these means were not in the expected direction.

SUMMARY AND DISCUSSION

There were three major findings in the current study. *First*, the data suggest that curvilinear paths are perceived as too flat and that the Arc-size Illusion has an important impact on judgments of traffic trajectories. These results are consistent with the research performed by Virsu. However, in all three of Virsu's studies (Virsu,1971a; Virsu,1971b; Virsu and Weintraub, 1971), participants were provided with no context and merely were asked to make judgments about arcs. The current study asked participants to imagine they were performing a real-world task, and the stimuli differed in that they contained a triangle representing an aircraft. Therefore, these results are important, because they suggest that this illusion warrants examination beyond pure, academic curiosity.

Second, and most surprising, the data suggest that increasing the size of the arc with a history line does NOT lessen the effects of the Arc-size Illusion. This finding is contrary to Virsu's findings (Virsu, 1971a; Virsu, 1971b; Virsu & Weintraub, 1971), in which the curvature of generic arcs was perceived more accurately by merely increasing the degrees of arc. However, the current findings are consistent with the findings of Palmer, Jago, Baty, and O'Connor (1980). They performed a series of studies in which they examined history and predictor lines. Palmer et al. had pilots view a CDTI and asked them to determine if an intruder would pass in front of or behind ownship. Pilots made these judgments when only the current positions of the aircraft were presented or when history lines were presented along with the current position. The addition of a history line did not yield a significant increase in the accuracy of pilots' judgments. Palmer et al. also asked a group of pilots to report the manner in which they would develop a CDTI. Four of six pilots suggested that they would not like a history line to appear on a CDTI. These pilots felt the history information would be redundant with the turn rate information provided by curvilinear predictors. The two pilots who indicated they would like a history line on a CDTI suggested that they would like either no predictor line or a predictor that did not include turn rate information. The Palmer et al. research and the current research suggest that an increase in arc size does not necessarily improve judgments. The particular context and/or particular stimulus features appear to be important.

Third, the data suggest that "flattening" is especially pronounced when the judgment location is relatively far and the predictor length is relatively short (e.g., the Constant Location and Constant Distance conditions for the 25 deg Predictor Length produced much "flattening"). However, the effect of the predictor length essentially disappears when the judgment location is at a distance that is proportional to the predictor length. Because traffic avoidance judgments typically involve judgments over a constant time period (e.g., "Where will my aircraft be in relation to Aircraft X in 5 minutes?"), this finding suggests that, in some cases, predictors for slower aircraft will cause no more problems than predictors for quicker aircraft.

Research is currently in progress, in an attempt to replicate these findings. The research in progress explores a wider range of predictor lengths than the present study. The aircraft icon also is being manipulated (i.e., chevron, circle, and no icon conditions are being examined). Such a manipulation will assist in determining if and how the icon might be responsible for participants' ignoring the history information. Finally, pulsing is being explored. Pulsing is currently utilized on the NASA Ames CDTI (c.f., Johnson, Battiste, & Holland Bochow, 1999). When pulsing is activated on the display, portions of the predictor line are bolded in succession. This bolding provides a sense that an object is moving along the predictor line and creates an illusion much like the phi phenomenon (i.e., apparent movement when two or more lights are flashed in succession). Virsu (1971b) suggests that the Arc-size Illusion may be a result of the human tendency to make saccadic, rectilinear eye movements (i.e., staircase-like eye movements). Because of this tendency, Virsu suggests that smaller arcs provide less corrective feedback to the brain, and as a result, are perceived as flatter. In other words, smaller arcs presumably yield fewer staircase-like eye movements. Therefore, the brain may interpret a smaller arc as having less curvature. Only in the presence of moving objects are smooth, pursuit eye movements possible (Sekuler & Blake, 1990). Such movements may serve to decrease "flattening" in general and may also lessen the Arc-size Illusion. A moving pulse should encourage smooth, pursuit eye movements and serve to lessen "perceptual flattening" as well as the Arc-size Illusion.

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